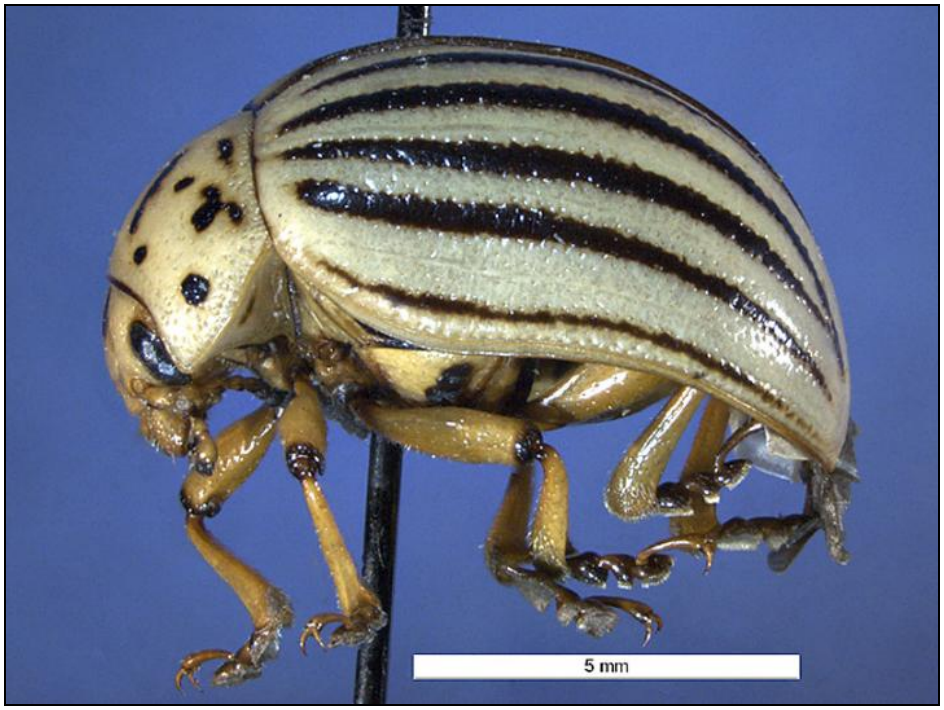
National Diagnostic Protocol for Colorado Potato Beetle, *Leptinotarsa decemlineata*



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Department of Agriculture

Prepared for the Subcommittee on Plant Health Diagnostic Standards (SPHDS)

This version of the National Diagnostic Protocol (NDP) for *Leptinotarsa decemlineata* is current as at the date contained in the version control box on the front of this document.

NDPs are updated every 5 years or before this time if required
(i.e. when new techniques become available).

The most current version of this document is available from the SPHDS website:
http://plantbiosecuritydiagnostics.net.au/resource-hub/priority-pest-diagnostic-resources/

Contents

1 INTRODUCTION

Leptinotarsa decemlineata (Say), the Colorado potato beetle (CPB) is one of the most destructive and widespread pests of cultivated potato. Both adults and larvae feed on the leaves and stems of the host plant, with complete defoliation occurring, unless effective control is achieved. Populations are liable to expand considerably under favourable weather conditions. Overwintered adult CPBs emerge from the ground in spring or early summer, depending on the climate and their physiological condition. A mass emergence over 1 or 2 days is commonly observed. Adult beetles usually fly for a short distance, or walk to the nearest potato field.

The main hosts of CPB are solanaceous crops and weeds (Appendix 8.1). These can either be as primary hosts, capable of supporting the full life-cycle (egg-adult) of CPB, or secondary hosts where adult CPB can complete maturity feeding, and final instar (L4) larvae can complete development to adult stage. Secondary hosts can play an important role by providing a "green bridge" for survival of CPB, in the absence of the primary hosts, or where primary hosts have harvested or died and only secondary hosts remain.

There is a considerable geographic variation in host utilisation by *Leptinotarsa decemlineata* (Say), both in the original and expanded portions of its geographic range (Hsiao, 1978, 1981, 1985; Weber and Ferro, 1997).

Australia has many species of native Solanaceae that have not been tested as hosts for *Leptinotarsa decemlineata* (Say) and which may potentially be reservoirs or "green bridges" for the pest.

2 TAXONOMIC INFORMATION

Order: COLEOPTERA
Family: Chrysomelidae
Subfamily: Chrysomelinae
Tribe: Doryphorini
Genus: *Leptinotarsa*
Species: *Leptinotarsa decemlineata* (Say)
(Some authors divide the Chrysomelinae to tribe Chrysomelini and subtribe Doryphorina; but the above hierarchy is more widely accepted).

Synonyms

Doryphora decemlineata Say 1824 (synonymy in Stål, 1863)
Doryphora decemlineata Roger in (Jermy and Balázs, 1990)
Leptinotarsa multitaeniata Stål 1859 (Stål, 1859) (synonymy in (Jacques, 1988)
Chrysomela decemlineata Say 1824 (new generic assignment Stål, 1865)
Leptinotarsa decemlineata Kraatz 1874 (Kraatz, 1874)
Leptinotarsa intermedia Tower 1906 (Tower, 1906)(synonymy in (Jacques, 1988)
Leptinotarsa oblongata Tower 1906 (Tower, 1906) (synonymy in (Jacques, 1988)
Leptinotarsa rubicunda Tower 1906 (Tower, 1906) (synonymy in (Jacques, 1988)
Polygramma decemlineata Mlelié in (Jermy and Balázs, 1990)
Polygramma decemlineata Mels in (Balás and Sáringer, 1982)
Leptinotarsa Chevrolat, 1837 = (*Chrysomela* Auct. = *Doryphora* Auct. = *Polygramma* Motschulsky, (1860)

Common name

Colorado potato beetle

3 DETECTION

3.1 Symptom description

Adults and larvae feed on the edges of leaves and may quickly strip the foliage of young plants. They eventually strip all leaves from the haulm. In some rare instances the tubers are also eaten. Characteristic black and sticky excrement is left on the stem and leaves by the larvae and adults.

3.1.1 Sites of infection/infestation

Activity may vary on secondary host plants.

Table 1. Life-stage activity in relation to potato, with similar pattern on other primary host plants.

Life Stage	Site of activity
Eggs	Oviposition in rows on undersides of leaves, occasionally on leaf stalks and stems, and rarely on soil
Larvae L1	Feed on leaf surface, causing skeletonisation; feed on leaf edges. Cannibalism under hot dry conditions
Larvae L2	Move to growing tips
Larvae L3	Feed on leaves starting at edges, petioles, stems causing defoliation
Larvae L4	Feed on leaves, petioles, stems causing defoliation; When mature, migrate to soil and burrow to various depths
Pre-pupa	in pupation chamber in soil
Pupa	Pupation chamber in soil.
Adult	Emerge from soil; walk or fly to host plants, feed extensively on leaves, occasionally tubers; mate and oviposit. Winter diapause - adults burrow in soil to diapause and hibernate over winter, and re-emerge in spring. Summer "aestival diapause" - adults may hide in above ground litter during extended dry periods in hot regions.

Table 2. Pattern of damage and activity of Colorado potato beetle on potato plants. Other primary hosts are affected in a similar way, but damage to secondary host plants may vary from this.

Plant part	Attacked	Insect Life Stage
Soil	N/A	L4 larvae burrowing; Pupae; Adults emerging and dispersing by crawling.
Root	Yes	Adults - Occasionally feed on tubers
Stem	Yes	Adults, Larvae. Black sticky excreta deposited
Leaves	Yes	Adults, Larvae. Main form of damage resulting in defoliation. Black sticky excreta deposited
Growing tips	Yes	Adults, Larvae. Black sticky excreta deposited.
Buds	Yes	Larvae - occasional damage in heavy infestations
Flowers	No	Not reported
Fruit and Seeds	No	Not reported

3.2 Stages of development

3.2.1 Eggs

The eggs are yellow or pale-orange, and elongate-oval ca 1.2-1.8 mm long and 0.7-0.8 mm wide (Figure 1). The most favoured oviposition site is on the underside of host plant leaves, where they are laid in batches of 25-30 [10-60, (Balás and Sáringer, 1982)]. Eggs are also often laid on leaf stalks and/or stems of potato plants. Oviposition may also occur on non *Leptinotarsa decemlineata* (Say)-host plants and even on lumps of soil. Female beetles glue eggs to the substrate using a special secretion. The eggs are placed on end with their long axis almost perpendicular to the leaf; with batches often forming irregular rows.

3.2.2 Larvae

The larval body is strongly convex dorsally with a large abdomen. The head bears 6 stemmata behind the antenna on each side and a pair of 5-dentate mandibles. Each of the three thoracic segments has a pair of 3-segmented legs, plus claw. The abdomen has 9 segments.

Colour changes with development; first instar cherry-red with shiny, black head and legs (Figures 2, 3); later instars becoming progressively carrot-red, then pale orange in final instar (Figure 4). Head, legs and posterior part of pronotum black to deep brown; two conspicuous rows of dark spots occur on the lateral aspects of the mesothoracic and abdominal segments 1 to 7, the uppermost surrounding the spiracles, and also segments 8 and 9 with dark dorsal plates. Setae when present are very small, some occur on the head, legs, pronotum, on the pigmented areas and ventrally.

Spiracles small, annular with black peritremes and situated on the mesothorax and first 8 abdominal segments. The body length of a full-grown larva is about 15 mm. Cox (1982) provides a detailed generic diagnosis of *Leptinotarsa* larvae and Peterson (1951) describes the first instar.

3.2.3 Pupae

The pupa is yellowish, bearing short setae on low, conical, brown tubercles. The head bears several short setae. The thorax with pronotum bears about 100 setae. Abdominal segments 1-6 with lateral expansion dorsal to spiracle, dorsally bearing about 48 short setae, laterally about 9 setae on large papilla ventral to spiracle. Apical abdominal segment bears a single, brown, median, sharply pointed urogomphus or spine. Spiracles are situated on mesothorax and abdominal segments 1-8: peritremes dark brown, but pale on abdominal segments 6-8. For further details, see Cox (1996).

3.3 Specimen Collection, Handling and Preservation

Live adults, larvae or eggs MUST NOT BE TRANSPORTED, unless considered essential, and then only in approved biosecure transport containers to be opened only in PC3 or QC3 secure containment facilities.

Adults, killed by standard methods (near boiling water; killing jar (cyanide, ethyl acetate); 70% ethanol) and pinned as dry mounted specimens or preserved in 70% ethanol.

Larvae, killed by standard methods (near boiling water; KAA preservative (kerosene - acetic acid - alcohol) and preserved in 70% ethanol.

Specimens for DNA analysis should be collected directly into absolute ethanol (adults or larvae).

Figure 1. Colorado Potato Beetle eggs on potato leaves (Hungary, 2004)

Figure 2. Colorado Potato Beetle L1 and L2 stage larvae (Hungary, 2004)

Figure 3. Colorado Potato Beetle L1 and L2 stage larvae (Hungary, 2004)

Figure 4. Colorado Potato Beetle L2 and L3 stage larvae (Hungary, 2004)

Figure 5. Colorado Potato Beetle adult on potato plant (Hungary, 2004)

Figure 6. Mating Colorado Potato Beetle adults on potato plant (Hungary, 2004)

4 IDENTIFICATION

Traditional taxonomic methods based on keys and descriptions are adequate for identification of *Leptinotarsa decemlineata* (Say) adults and larvae. Immature stages of CPB are short-lived and unlikely to be used for diagnosis. The descriptions and images in this document are sufficient for identification of the pest, the beetle is very distinctive and can be easily recognised morphologically by those with general beetle taxonomy knowledge. However it must be noted that some native Australian Chrysomelinae may not be easily distinguished from CPB by a non-specialist.

4.1 Morphological methods

4.1.1 Identification keys

Html key: http://www.cals.uidaho.edu/edcomm/keys/main.htm. University of Idaho Identification keys for insect pests in the Pacific Northwest field crops.
Characters listed for Chrysomelinae often do not apply to many native Australian taxa (Reid, 2006). It is useful to compare Colorado Potato Beetle with native Australian Chrysomelidae provided by Reid, 2006 (http://www.mapress.com/zootaxa/2006f/zt01292p040.pdf)

4.1.2 Adult identification

Identification of subfamily Chrysomelinae

- Round, or oval convex; usually brightly coloured
- Head inserted into the prothorax to the eyes
- Eyes feebly emarginate
- Antennae moderately long, apical segments somewhat enlarged
- Antennal insertions widely separated
- Prothorax usually broad and convex, lateral margins well defined, frequently emarginate in front
- Procoxae transverse, widely separated
- Third tarsal segment entire, not bilobed.
- Elytra convex, covering abdomen, epipleura well defined.

Identification of Doryphorini

- Round, or oval convex; usually brightly coloured
- Procoxal cavities externally open
- Claws simple, separate at base, usually divergent
- Apical segment of maxillary or labial palpi maxillary various

Identification of* genus *Leptinotarsa

- Claws divergent, or at least separated at base
- Apical segment of maxillary palp truncate
- Fore femora of both sexes normal
- Mesosternum not raised below level of the prosternum

Identification of Leptinotarsa decemlineata (Say)

- Head and pronotum with black maculations (Figures 8 and 9)
- Each elytron with 5 vittae (stripes) extending from base of elytra to the apex (Figures 10 and 11)

- Elytral punctation slightly irregular outlining vittae (Figure 12).
- Abdomen and legs pale yellow to flavous, joints and tarsal segments brown to black (Figure 13)
- Visible sternites I-V with black spot at lateral margin, I-IV with black, oblong spots on either side of midline (Figure 14).

Figure 8 and 9. Head and Pronotum with black maculations *of Leptinotarsa decemlineata*

Figure 10 and 11. Each elytron with 5 vittae (stripes) extending from base of elytra to the apex

Figure 12. Elytral punctation slightly irregular outlining vittae

Figure 13. Abdomen and legs pale yellow to flavous, joints and tarsal segments brown to black

Figure 14. Visible sternites I-V with black spot at lateral margin, I-IV with black, oblong spots on either side of midline, sometimes with small, additional black spots in between lateral and median spots.

4.1.3 Likelihood of misidentification

Colour pattern variations within *Leptinotarsa decemlineata* (Say) have often been observed. The most common variations occur in the vittae. There may be a short interruption of one or more of the vittae, or in some cases vittae are connected at one or more places by lines of the same thickness and same colour as the vittae. One very rare melanistic variant is known where the beetle's colour is uniformly very dark brown - black (Kaszab, 1963). However, such extreme variation needs to be confirmed by detailed comparison with the few known specimens.

There are no native or introduced Chrysomelid beetles belonging to the genus *Leptinotarsa* in Australia. The truncate maxillary palps, elytral vittae and the maculate pronotum are so typical that misidentification is very unlikely. However there are three other *Leptinotarsa* species that show similarities to CPB. Their possible occurrence in quarantine samples and/or material of overseas origin may result in misidentification of these beetles.

The following references should be of assistance in identification: Both et al. (1990); Jacques, (1988); Riley et. al., (2002); Warchałowski, (2003); Matthews and Reid, (2002).

The following five *Leptinotarsa* species may be mis-identified as *L. decemlineata* (Say). None are present in Australia.

4.1.3.1 **Leptinotarsa defecta *(Stål)***

Synonyms: Myocorina defacta Stål, 1859, *Chrysomela defect* (Stål), 1859

Not present in Australia

Figure 15. Only two shortened vittae present on each elytron

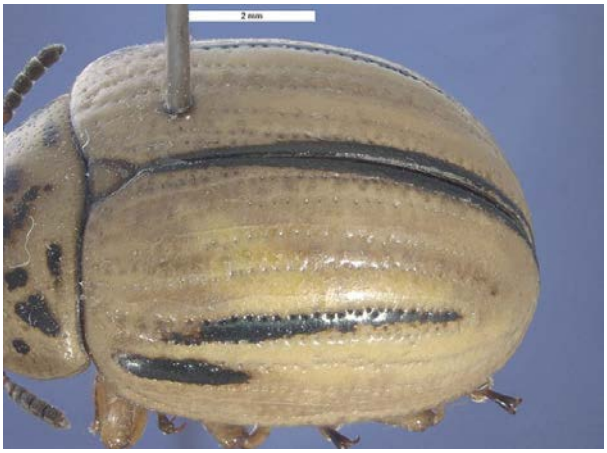

Figure 16. Coarse elytral punctures in very regular rows

Figure 17. Legs: Dark spots are present on femora

External differences
Only 2 shortened vittae present on each elytron
Coarse elytral punctures in very regular rows
Legs: dark spots are present, especially on femora

Hosts
Solanum eleagnifolium L. - horse nettle; *Solanum tridynamum*.

Recently this species has been introduced to South Africa together with *Leptinotarsa texana* Schaeffer as biological control agents for the control of their main host, *Solanum eleagnifolium* Cavanilles - the silverleaf nightshade (Olckers and Zimmermann 1991; Olckers et. al. 1999; Klein, 2002).

4.1.3.2 Leptinotarsa juncta *(Germar)*

Synonyms
Chrysomela juncta Germar, 1824
Polygramma juncta Dejean, 1836
Doryphora juncta Rogers, 1854
Chrysomela juncta Stål, 1863
Myocoryna juncta Crotch, 1873
Leptinotarsa juncta Linell, 1896

Not present in Australia

External differences

- Vitta 2 does not reach apex of elytra
- Vittae 3 and 4 connect at apex of elytron, space between them black
- Black spot on outer margin of femur
- Abdomen: sterna I-V with 6 black discoidal spots and sterna VI with 2 black spots
- Coarse elytral punctures in very regular rows outlining vittae

Hosts
Solanum carolinense L. - horse nettle.

Its accepted common name - false potato beetle - is very misleading. It tends to suggest that it may occur on cultivated potato though it has never been collected on *Solanum tuberosum* plants.

4.1.3.3 Leptinotarsa texana *Schaeffer*

Synonyms:
Leptinotarsa undecemlineata texana Schaeffer, 1906
Leptinotarsa texana Brown, 1961

Not present in Australia

Figure 18. Each elytron with 4 vittae

Figure 19. Vitta 1 is shorter than the others

Figure 20. Coarse elytral punctures in very regular rows outlining vittae; rows 2 and 9 bordering vittae; row 10 does not border lateral margin

Figure 21. Legs flavous, without dark spots on femora, or darkened joints and tarsi

External differences

- Each elytron with 4 vittae
- Vitta 1 is shorter then the others
- Coarse elytral punctures in very regular rows outlining vittae; rows 2 to 9 bordering vittae; row 10 does not border a vitta near lateral margin
- Legs flavous, without dark spots on femora, or darkened joints and tarsi

Hosts
Primary host: *Solanum eleagnifolium* Cavanilles
Secondary hosts: *Solanum dulcamara, S. carolinense, S. rostratum*, and *S. melongena*.

Recently this species has been introduced to South Africa together with *Leptinotarsa defecta* (Stål) as biological control agents for the control of their main host, *Solanum eleagnifolium* Cavanilles - the silverleaf nightshade (Olckers and Zimmermann 1991; Olckers et. al. 1999; Klein, 2002).

4.1.3.4 Leptinotarsa tumamoca *Schaeffer*

Synonyms: No synonym known.

External differences

- Head immaculate, reddish-brown
- Abdomen unicolorous, reddish-yellow
- Legs unicolorous, reddish-yellow

Hosts
Only known host: *Physalis acutifolia* Gray, common name: sharpleaf groundcherry, an invasive weed of arid lands.

4.1.3.5 Leptinotarsa undecemlineata (Stål)

Synonyms
Polygramma undecimlineata Chevrolat, 1836
Myocorina undecemlineata Stål, 1859
Myocorina signaticollis Stål, 1859
Chrysomela signaticollis (Stål, 1863)
Leptinotarsa signaticollis Jacoby 1883
Chrysomela undecemlineata (Stål, 1863)
Leptinotarsa undecemlineata Jacoby 1883
Leptinotarsa angustovittata Jacoby 1891
Leptinotarsa diversa Tower, 1906

Not present in Australia.

External differences

- Vitta 1 shorter than other 4 and adjacent to the sutural margin
- Vitta 2 joins the sutural margin ¾ the way down the elytron
- Legs unicolorous, black
- Abdomen unicolorous, black

Hosts
Solanum mitlese, *S. lanceolatum* Cav., *S. ochraceoferrugineum* (Dunal).

This species is rarely found even within its natural distribution area.

4.2 Molecular methods

No references or data on molecular or DNA based identification methods were found in the literature. Such methods are likely to be superfluous for routine diagnostic identification, given the clear and distinctive morphological features of CPB. However, molecular techniques may be of value in determining the origin of an incursion, or of determining biochemical or physiological attributes, such as pesticide resistance profiles of CPB.

5 CONTACT POINTS FOR FURTHER INFORMATION

5.1 Present taxonomic capabilities in Australia

Entomologists with sufficient taxonomic and diagnostic skills exist in Museums, Departments of Agriculture or Primary Industries, Universities or CSIRO, to competently identify CPB. The information in this protocol and on the PaDIL website should be sufficient to accurately identify *Leptinotarsa decemlineata* (Say).

However, it should be noted that only one specialist taxonomist is currently working on Chrysomelid beetles in Australia.

If required, suitably preserved samples requiring identification or confirmation as *Leptinotarsa decemlineata* (Say) or related species, can be sent to the Diagnostics Entomologist in the Western Australia Department of Agriculture.

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6 ACKNOWLEDGEMENTS

This protocol was developed from information on the Colorado Potato Beetle sourced from the Plant Health Australia Pest Risk Review and the PaDIL Toolbox. Andy Szito, Department of Agriculture, WA.

This protocol was peer reviewed and verified by Dr Adam Slipinski, Systematics Identity and Relationships, CSIRO Ecosystem Sciences - Black Mountain, ACT, Australia.

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8 APPENDIX

8.1 Host range

The main hosts of CPB are solanaceous crops and weeds (Table 3), however they are also know to attack other weeds such as groundcherry and climbing nightshade (Table 4 and 5).

Table 3. Primary host plants (Family Solanaceae) capable of supporting the full life-cycle (egg-adult) of CPB

Genus and species	Common name	Comments	Reference
Solanum tuberosum	potato		Bruess (1940); Hsiao (1981)
Solanum melongena	egg-plant		Bruess (1940); Hsiao (1981)
Lycopersicum esculentum	tomato	Some varieties only	Bruess (1940)
Atropa belladonna	deadly nightshade		Jermy and Balázs (1990)
Solanum rostratum	buffalo burr		Hsiao (1981, 1986)
Solanum heterodoxum	melon-leaf nightshade		Hsiao (1986)
Solanum fructo-tecto			Hsiao (1986)
Hyosciamus niger	black henbane		Jermy and Balázs (1990):
Solanum viarum	tropical soda apple	Weed introduced into Florida	Cuda et al (2004), McGovern (1994), Sudbrink et al. (2000),

Table **4.** Secondary hosts (Family Solanaceae) where adult CPB can complete maturity feeding, and final instar (L4) larvae can complete development to adult stage.

Genus and species	Common name	Comments	Reference
Datura stramonium L.	common thornapple	Adults and L4 larvae	Balás and Sáringer (1982)
Solanum dulcamara L.	climbing nightshade	Adults and L4 larvae	Balás and Sáringer (1982)
Solanum nigrum L.	black nightshade	Adults and L4 larvae	Balás and Sáringer (1982)
Lycium sp.	desert thorn	Adults only	Jermy and Balázs (1990):
Physalis spp.	groundcherry	Adults only	Jermy and Balázs (1990):

Table 5. Potential secondary hosts (Family Solanaceae) where CPB feeding has been observed, but for which there are no detailed data on survival of specific developmental stages.

Genus and species	Common name	Comments	Reference
Nicotiana tabacum L.	cultivated tobacco		Bruess (1940)
Solanum carolinense.	carolina horsenettle.		Hsiao (1981)
Solanum dimidiatum.	robust horsenettle		Hsiao (1986)
Solanum diversifolium	prickly sunplant	Adults only	Hsiao (1986)
Solanum dulcamara	climbing nightshade		Hsiao (1981)
Solanum elaeagnifolium	silverleaf nightshade		Hsiao (1981)
Solanum laciniatum	kangaroo apple		Hsiao (1986), Jermy and Balázs (1990):
Solanum marginatum	white-margined nightshade		Bruess (1940)
Solanum sarachoides	sugar nightshade		Hsiao (1981)
Solanum sysimbriifolium	sticky nightshade		Barber (1933)
Solanum triquitrium			Hsiao (1986)

8.2 Life History

Overwintered adult CPBs emerge from the ground in spring or early summer, depending on the climate and their physiological condition. A mass emergence over 1 or 2 days is commonly observed. Adult beetles usually fly for a short distance, or walk to the nearest potato field. Host plants are located mostly by chance, through random searching, although potato plant odour is attractive to adult beetles. The adults must feed before mating and maximum food consumption occurs at 25°C. The developmental threshold is approximately 10ºC. The adults mate and oviposition follows within 1 or 2 days. A minimum of 51 degree-days (DD above 10ºC) after eclosion is needed before the onset of egg laying (Alyokhin and Ferro, 1999).

Oviposition occurs when temperature is in the range 15-30°C. Batches of 10-60 eggs are laid, usually in several often irregular rows on the lower surface of leaves. Egg laying usually continues over several weeks until midsummer, with each female laying in average 500-1000 eggs. The larvae hatch using egg bursters or oviruptors situated on the meso- and metathorax and abdominal segment 1 (Cox, 1988). They hatch in 4-12 days, provided that temperatures are above 12°C, and emerging larvae start to feed immediately.

After freeing themselves from the chorion, the larvae partly or entirely consume the chorion before feeding on leaf tissue. Without doing so they will die (Balás and Sáringer 1982). Feeding is continuous, except during moulting. Three moults (4 instars) occur over 2-3 weeks, at an optimum temperature of 40°C. The larvae are hardy and resistant to unfavourable weather, although heavy rain and strong winds may lead to high mortality, especially in earlier instars. Cannibalism during the first instar is particularly common when hot dry conditions prevail.

Larvae from the same egg batch remain grouped together on the lower leaf surface until the first moult, after which they migrate to the terminal buds. By the final or fourth instar, they attack leaf petioles and stems. The larval stage lasts usually 15-21 days. Fully developed larvae descend to the ground and bury themselves in the soil at varying depths to pupate. Pupation occurs in smoothly lined cells with the pupal period lasting 6-12 days. After turning to adults they remain in the pupal cell for a further 3-4 days. Emergence is followed by a 5-10 day maturity feeding period. During this time adults consume 2-3 times more leaf material than during their entire larval stage. The number of generations varies between approximately four (in the hottest areas with the cycle of egg to adult completed in 30 days) to one full and one partial generation near the colder extremes. In cold areas where only one partial generation is produced, *Leptinotarsa decemlineata* (Say) cannot establish permanently.

The requirement for development of one full generation is a period in summer of at least 60 days of temperatures greater than 15°C and winter temperatures not falling below -8°C, is well met by the climatic conditions prevalent in the potato production regions of Australia. It is expected that 2 to 4 generations per season would be completed in the event of *Leptinotarsa decemlineata* (Say) establishing in Australia.

In warmer areas, the fecundity of first-generation adults is higher than succeeding generations. In some areas the number of eggs laid by each successive generation decreases by approximately 25% per month during the summer.

In the northern part of the *Leptinotarsa decemlineata* (Say) range in Europe, the newly emerged first generation beetles feed and then burrow 250-400 mm into the soil (usually deeper in dry sandy soils than in wetter clay soils) where they enter diapause and hibernate over winter. Mortality during hibernation averaged 30% in the Ukraine, but may be as high as 83%, mainly due to fungal and bacterial infections (Koval, 1984). Burrowing in the ground during hibernal diapause enables *Leptinotarsa decemlineata* (Say) to escape the severe cold and contributes to its success as a persistent pest in temperate regions. Adult *Leptinotarsa decemlineata* (Say) are capable of perennial diapause in extreme climates. These strategies of adaptation provide optimal synchronisation of the species to its host plants in diverse geographical regions. In some areas of Western Australia and Queensland CPB may not need to go into true hibernation, with only a slowing down in activity over winter.

In temperate regions, photoperiod is the most important factor for inducing 'hibernal diapause' in teneral adults of CPB, but ambient temperatures and food quality may have modifying effects (Hsiao, 1988). This species is a typical 'long-day' insect that enters diapause after exposure to a critically short photoperiod, which is a factor that varies with latitude. In general, populations from latitudes nearer the equator of the Northern hemisphere require a shorter photoperiod for diapause induction than those from more northerly latitudes (de Wilde and Hsiao, 1981). Critical photoperiods approach 16 hours for northern populations (latitude 45°N) (Tauber et al., 1988) and decline to about 12 hours for southern populations (latitude 32°N).

The proportion of first-generation adults entering diapause in a particular region varies between seasons as a function of ambient temperature and between fields initially colonised at different times. Thus overwintering adults colonising fields relatively late in the spring may produce only one generation, whilst two generations may be produced in early-colonised fields (Voss et al., 1988).

The 'aestival diapause' of populations from warmer, arid regions is induced by deterioration in the quality and/or a shortage of their host plants. These populations hibernate above ground and resume feeding and reproduction once moisture and host-plant conditions become favourable.

8.3 Dispersal

Walking across ground by adult *Leptinotarsa decemlineata* (Say) is an important short range dispersal factor. Adults are capable of walking at a maximum speed of approximately 10 mm/s on bare ground and may move several hundred metres in the field in this manner. Walking speed is strongly affected by height and density of vegetation (Ng and Lashomb, 1983). There may be non-specific plant olfactory cues that help walking beetles in locating host plants (Visser, 1988; Jermy, 1958). Other workers have emphasised chance encounter and visual cues for host finding (Jermy et al., 1988).

Flight with wind assistance is the main mechanism for medium to long distance dispersal. Despite periods of walking activity (Voss and Ferro, 1990), natural spread of *Leptinotarsa decemlineata* (Say) over large areas is by windborne dispersal, particularly for the spring generation. Short flights up to 3 kms are common, but under conditions of high temperatures and storms, when large numbers of CPBs take flight, wind-assisted migration of up to 160 kms has been reported (Voss and Ferro, 1990).

Three distinct types of flight have been reported for CPB, and these differ in characteristics as well as in function (Voss and Ferro, 1990). Both sexes perform all three types of flight behaviour. Short range or trivial flight occurs within the host habitat. This is a low altitude flight with frequent turning. It may serve to disperse egg laying sites within a field, mate finding by the males and/or sampling the habitat for higher quality resources. Short-range flight can be triggered by harvesting of crop host plants. In this circumstance, CPB adults may congregate on walls of buildings or other vertical surfaces.

Long range or migratory flight is in a straight line, often down-wind. There is no searching for food plants immediately after take-off. Long range flight is typical for post-diapause adults, which have large energy reserves. It has also been observed later in the season, and most likely serves to disperse egg laying sites more widely than just within a suitable habitat.

Diapause flight takes the beetles from summer habitats to preferably uncultivated areas where they burrow into the soil to diapause. Diapause flight is at low altitude and starts with a spiralling flight to approximately 5 m altitude, with orientation to tall vegetation (Weber and Ferro, 1997).
There are usually two periods of flight activity concurrent with post-diapause and appearance of the first generation adults in the field (Voss and Ferro, 1990).

Human-aided dispersal

Adult CPBs are readily transported as "hitch-hikers" on non-host plants and produce, particularly leafy vegetables and grain that has been grown in fields where potatoes have previously been included in the rotation (FERA, 2001). Adults and larvae can also easily be transported on potato plants and tubers, and in all forms of packaging used to transport such material.